Anomalous trilinear and quartic $WW\gamma$, $WW\gamma\gamma$, $ZZ\gamma$ and $ZZ\gamma\gamma$ couplings in photon induced processes at the LHC

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We first report on possible measurements at the LHC using the first data and a luminosity of 10 pb^{-1} of W and Z pair production via two-photon exchange. This measurement allows in particular to increase the present sensitivity on $WW\gamma\gamma$ and $ZZ\gamma\gamma$ quartic anomalous couplings from the LEP experiments by almost three orders of magnitude. We also discuss the possible improvements on quartic and trilinear anomalous couplings at high luminosity at the LHC using new forward proton taggers to be installed at 220 and 420 m from the CMS or ATLAS detectors.

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1. Anomalous quartic $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings at LHC

The non-abelian gauge nature of the Standard Model (SM) predicts the existence of quartic couplings $WW\gamma\gamma$ between the W bosons and the photons which can be probed directly at the Large Hadron Collider (LHC) at CERN. The quartic coupling to the Z boson $ZZ\gamma\gamma$ is not present in the SM. High energy colliders such as the incoming LHC are the natural place to look for anomalous quartic couplings between the photon and the W or Z bosons. The process we want to study at the LHC corresponds to $pp \rightarrow pWWp$. In this photon-induced process, the two quasi-real photons interact through the exchange of a virtual W or Z, leading to a pair of Ws or Zs in the final state. The advantage of this kind of events is that they are extremly clean, there are two Ws (or Zs) which can be detected in the ATLAS or CMS central detectors while the intact proton leave undetected in the beam pipe.

To study the sensitivity on quartic anomalous couplings at the LHC, we restrict ourselves to the implementation of the genuine quartic anomalous $\gamma\gamma WW$ and $\gamma\gamma ZZ$ using the lowest dimension operators possible in the Lagrangian [1] performed in the FPMC generator [2]. The implemented survival probability is 0.9 for QED events [3].

The current best 95% confidence level (C.L.) limits on the parameters of quartic anomalous couplings were determined by the OPAL Collaboration [4] at LEP and are given in Table 1.

We study the sensitivity on quartic anomalous a_0^W and a_C^W couplings using the first data to be taken at the LHC, and namely a luminosity of 10 (or 100) pb^{-1} which can be accumulated in a couple of days or weeks at a center-of-mass energy of 10 TeV. To simplify the study, we limit ourselves to the leptonic decays of the W pair to electrons or muons. The signal is characterised by the presence of two high transverse momentum (p_T) leptons (electrons or muons) reconstructed in the ATLAS central detector, and the absence of any other reconstructed object or energy flow since the scattered protons leave undetected in the beam pipe.

Let us now discuss each background in turn implemented in FPMC (the survival probability for double pomeron exchange processes is assumed to be 0.03 at LHC energies [3]). The non-diffractive W pair production is suppressed by requesting the presence of two leptons and nothing else in the ATLAS detector since the inclusive background always shows some hadronic activity in the calorimeter or in the forward part of the tracking detector. The dilepton production through photon exchange (QED process) is suppressed by requesting the presence of a leading lepton with $p_T > 160$ GeV, and of missing energy greater than 20 GeV, which is natural when one requests the presence of two Ws. The pure SM W pair background (without any anomalous couplings) via photon exchange is small since the value of the cross section is low (62 fb) and it is further suppressed by requiring a reconstructed lepton with $p_T > 160$ GeV. The diffractive production of dileptons or W pairs via double pomeron exchange (DPE) leads to a negligible background after the exclusivity cut. After all cuts, the background is found to be negligible. The reach on the different anomalous couplings is given in Table 1.

At higher luminosity, the forward proton detectors [5] located at 220 and 420 m along the beam direction far away from the ATLAS or CMS interaction points are nedeed to remove the pile up background using the timing detectors (the scattered protons can be originated from additional soft interactions with respect to the hard interaction producing the W or Z pairs). With a luminosity of about 100 fb^{-1}, the sensitivity on anomalous quartic couplings can be improved further by
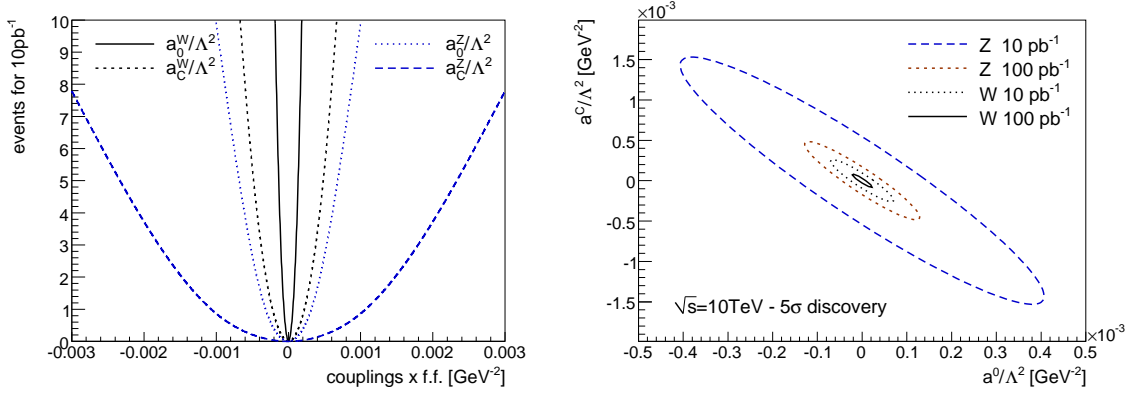
Figure 1: Left: Number of signal events after cuts as a function of the value of the quartic anomalous coupling for 10 pb^{-1} at the LHC. Right: 5σ discovery contours for the WW and ZZ quartic anomalous couplings at $\sqrt{s} = 10$ TeV for luminosities of 10 and 100 pb^{-1}.

two orders of magnitude. This is specially interesting to test higgless models which predict the existence of quartic anomalous couplings at one loop of the order of a few 10^{-6} GeV^{-2}.

Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 10$ (100) pb^{-1}	
		5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$2.2\ 10^{-4}$ $(7.3\ 10^{-5})$	$1.0\ 10^{-4}$ $(3.3\ 10^{-5})$
a_C^W/Λ^2	[-0.052, 0.037]	$5.9\ 10^{-4}$ $(2.4\ 10^{-4})$	$3.5\ 10^{-4}$ $(1.1\ 10^{-4})$
a_0^Z/Λ^2	[-0.007, 0.023]	$1.0\ 10^{-3}$ $(3.7\ 10^{-4})$	$5.2\ 10^{-4}$ $(1.7\ 10^{-4})$
a_C^Z/Λ^2	[-0.029, 0.029]	$3.0\ 10^{-3}$ $(1.3\ 10^{-3})$	$1.8\ 10^{-3}$ $(5.9\ 10^{-4})$

Table 1: Limits on anomalous coupling coming from the LEP OPAL experiment. Sensitivity at low luminosity. The 5σ discovery potentials as well as the 95% C.L. limits are given for 10 pb^{-1} and 100 pb^{-1} in parenthesis.

2. Anomalous trilinear couplings at LHC

At the LHC, it is also possible to study the anomalous trilinear couplings $WW\gamma$ and $ZZ\gamma$. We consider the modification of the $WW\gamma$ triple gauge boson vertex with additional terms conserving $C-$ and $P-$ parity separately, that are parametrized with two anomalous parameters $\Delta\kappa^\gamma$, λ^γ [6]. In order to obtain the best $S/\sqrt{B}$ ratio, the ξ acceptance was further optimized for the λ^γ parameter. The event is accepted if $\xi > 0.05$. In case of $\Delta\kappa^\gamma$, the full acceptance of the forward detectors is used since the difference between the enhanced and SM cross section is almost flat around relevant values of the coupling $|\Delta\kappa^\gamma|$. For 30 fb^{-1}, the reach on $\Delta\kappa^\gamma$ and λ^γ is respectively 0.043 and 0.034, improving the direct limits from hadronic colliders by factors of 12 and 4 respectively (with respect
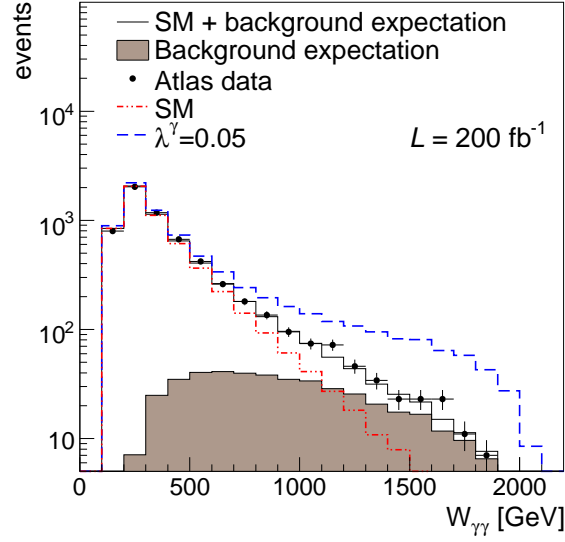
Figure 2: Distributions of the $\gamma\gamma$ photon invariant mass $W_{\gamma\gamma}$ measured with the forward detectors using $W_{\gamma\gamma} = \sqrt{s\xi_1\xi_2}$. The effect of the λ^γ anomalous parameter appears at high $\gamma\gamma$ invariant mass (dashed line). The SM background is indicated in dot-dashed line, the DPE background as a shaded area and their combination in full line. The black points show the ATLAS data smeared according to a Poisson distribution.

to the LEP indirect limits, the improvement is only about a factor 2). Using a luminosity of 200 fb^{-1}, present sensitivities coming from the hadronic colliders can be improved by about a factor 30, while the LEP sensitivity can be improved by a factor 5.

It is worth noticing that many observed events are expected in the region $W_{\gamma\gamma} > 1$ TeV where beyond standard model effects, such as SUSY, new strong dynamics at the TeV scale, anomalous coupling, etc., are expected (see Fig. 2). It is expected that the LHC experiments will collect 400 such events predicted by QED with $W > 1$ TeV for a luminosity of 200 fb^{-1} which will allow to probe further the SM expectations.

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